Developing Evapotranspiration Data for Idaho's Treasure Valley using the Surface Energy Balance Algorithm for Land (SEBAL)

Year 2000

By:
William J. Kramber
Idaho Department of Water Resources
1301 N. Orchard Street
Boise, Idaho 83706

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INTRODUCTION

The Surface Energy Balance Algorithm for Land (SEBAL) is a satellite image-processing model for computing evapotranspiration (ET) maps for large areas. SEBAL is comprised of twelve computational steps that predict a complete radiation and energy balance for the earth's surface along with fluxes of sensible heat and ET. SEBAL uses digital image data collected by Landsat or other remote-sensing satellites measuring visible, near-infrared, and thermal infrared radiation. ET is computed as a component of the energy balance on a pixel-by-pixel basis.

ET data was developed with SEBAL for the Treasure Valley of Idaho for the year 2000. The data will be used for hydrologic modeling and regional planning.

DATA

Landsat Data

The USGS Earth Explorer website (http://edcsns17.cr.usgs.gov/EarthExplorer/) was used to help select and order images. The website allows users to search the archive by selecting images from path rows for time periods of interest. Image metadata and preview images are available.

Landsat images 42/29 and 42/30 covered the study area. All Landsat 5 and Landsat 7 images from March 1 to October 31 were evaluated for cloud cover by looking at preview images. Images with a monthly interval were desired to develop seasonal ET data. Landsat 5 images were selected from: 4/30, 6/1, and 10/7. Landsat 7 images were selected from 3/21, 6/25, 7/27, and 8/28.

A total of 14 images were purchased for this area; two images for each of the 7 dates. The 3/21 image was the only one with some cloud cover; in the NW and NE parts of the image. The two images for each date were mosaicked and clipped to the study area to process as one image.

Digital Elevation Model

A Digital Elevation Model (DEM) was used because the SEBAL Mountain Model was applied for this project. The Mountain Model accounts for differences in slope, aspect, and elevation. The Flat Model assumes a flat surface.

The DEM used was developed from the USGS National Elevation Data (NED). The NED are the best available 1:24,000-scale elevation data; they are mosaicked into large blocks, and processed to remove any gaps and artifacts. The NED at IDWR is in 250K tiles with z-units of centimeters. Six 250K tiles were mosaicked and clipped to the study area, to precisely match the Landsat data. The z-units were converted from centimeters to meters.

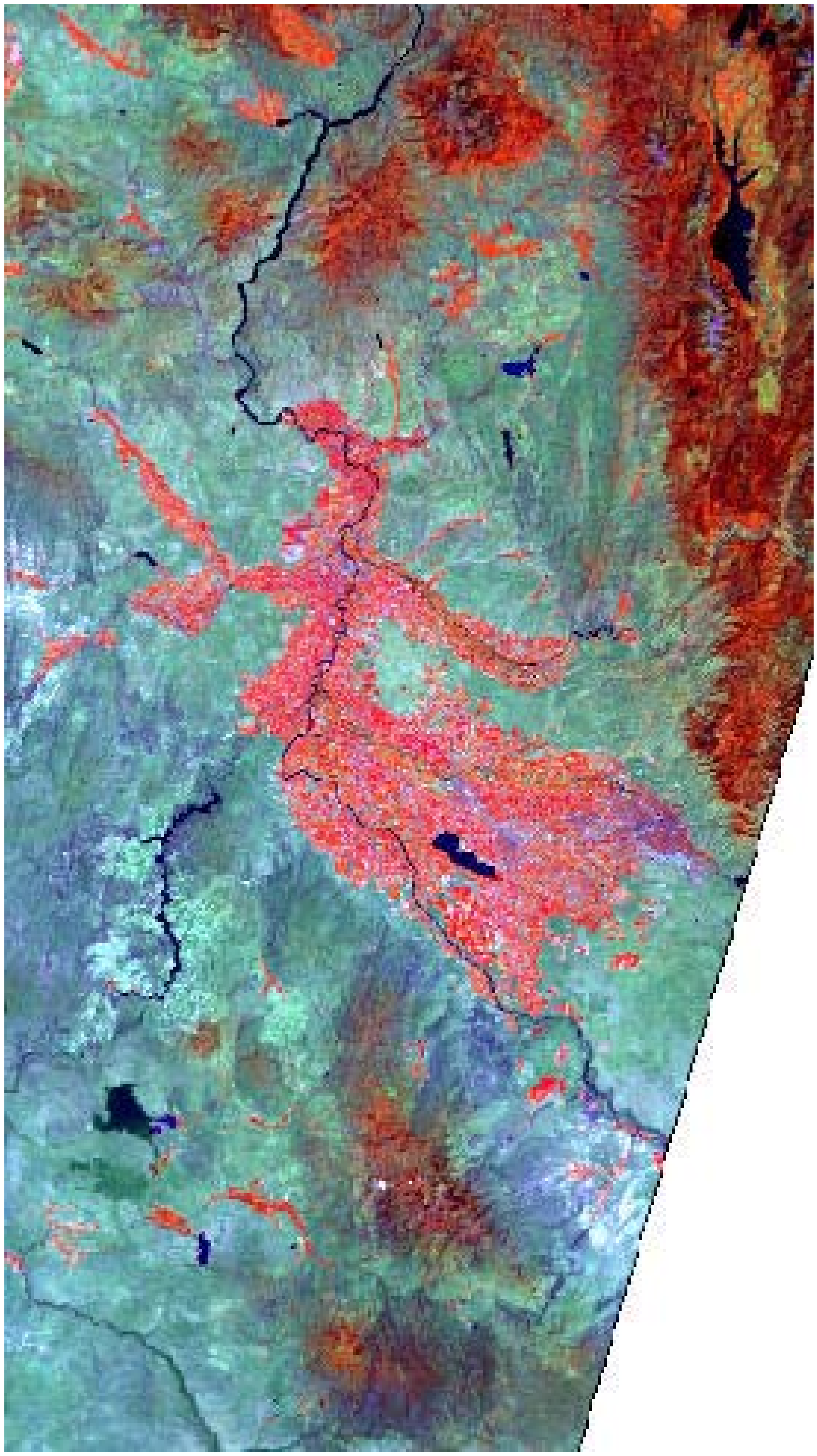


Figure 1. Landsat images from 6/25 mosaicked and clipped.

Land Cover Data

Land cover data are not necessary for SEBAL but it does improve estimates of surface roughness, soil heat flux, and surface emissivity. The images from 6/25, 7/27, and 8/28, were used to develop land cover data. Bands 2, 3, 4, 5, 6, and 7 from all three dates were combined into one image and clipped to the study area. A Principal Component Transformation was applied to reduce the data dimensionality from 18 bands to 6 components. The ISODATA unsupervised classification algorithm was applied to develop 250 spectral classes. ISODATA parameters were set at: maximum iterations 20, convergence threshold 0.950, skip factor 3. Spectral classes were grouped into 12 land cover classes with the help of: the Flicker Utility, GeoTools Dendogram, and the 1992 USGS National Land Cover Data (NLCD). The NLCD was used primarily to help classify desert grass and sagebrush.

The 12 land cover classes and their class-codes are:
1 water,
2 city,
3 agricultural crops,
4 trees,
5 desert grass,
6 desert sagebrush,
7 bare soil,
8 burns,
9 salt,
10 basalt,
21 mountain forest (slope > 5 degrees)
22 mountain forest (slope < 5 degrees)

Weather Data

SEBAL uses windspeed, solar radiation, dew point temperature, air temperature, and reference ET data. Precipitation data is also used to determine the wetness of an image and for computation of a water balance if needed. Dr. Rick Allen of the University of Idaho Kimberly Research and Extension Center (http://www.kimberly.uidaho.edu/) obtained and processed the weather data for this project. The weather data was downloaded from the AgriMet website (http://mac1.pn.usbr.gov/agrimet/) for the Nampa and Parma stations. The weather data was processed with the REF-ET program (http://www.kimberly.uidaho.edu/ref-et/) to develop reference ET data. Dr. Allen also computed a water balance for bare soil for all the image dates, to determine if the Reference ET Fraction (EtrF) equaled zero. All the dates were zero except for 3/21, which was 0.5. All weather data used in the SEBAL models and spreadsheets was the average of the Nampa and Parma weather data.

For the hourly weather data, the actual time the weather data was measured did not correspond precisely with the time the images were acquired. A formula was used to interpolate between two measured values to produce a value for the satellite overpass time. This formula has since been put into a spreadsheet by Rick Allen: SEBAL_Interpolation_Instantaneous_Weather.xls.

PROCESSING 24 HOUR ET

The SEBAL Mountain Model is implemented with a series of 12 models in the ERDAS Spatial Modeler. Data for the models is also calculated by EXCEL spreadsheets (ModelConstants.xls and Calculations_for_05_H_Automatic_GMD_Model.xls (H_auto.xls)). The Mountain Models and spreadsheets were developed by Dr. Rick Allen, and two PhD students, Masahiro Tasumi and Ricardo Trezza. All the models are run in sequence for each image date. User interaction is required for model inputs, to verify the output images, and to select Hot and Cold pixels that are used for internal calibration.

Information needed for the ModelConstants.xls spreadsheet are: image date, image overpass time, image center in decimal degrees, daily and instantaneous dewpoint temperature, and windspeed at overpass time.

Information needed for the H_auto.xls spreadsheet are: instantaneous Reference ET (ETr); and for the Cold and Hot pixels: coordinates, elevation, EtrF, surface temperature, DEM adjusted surface temperature, net radiation (Rn), soil heat flux (G), surface roughness (Zom), and wind speed at 200m.

The models and their output(s) are:

001 cosine_slope, sine_slope, cosine_aspect, sine_aspect (all from DEM)
002 ra24
003 rso24, need daily dew point output from REF-ET program
005 cosine_theta
006 rso_instantaneous, need hourly dew point output from REF-ET program
007 transmittance (from DEM)
01 Ts, Ts_DEM, emissivity, LAI, NDVI, albedo (Different models for Landsat 5 and 7)
02 Rn, G, need to select hot and cold pixels
03 Zom, U200, need elevation of weather station(s)
04 U*1, rah1
05 H_iterations, needs hot and cold pixel values for Ts, Ts_DEM, Rn, G, Zom, U200
06 ET24, ETrF

A ET24 legend was developed with a series of color ramps using the following colors: 0 gold, 2 tan, 4 turqouise, 6 charteuse, 8 dark green, 10 very dark green (R:0.0, G:0.2, B:0.0).

Selecting the Hot and Cold Pixels

Hot and cold pixels are selected to calibrate the model. The cold pixel is chosen from an agricultural field of full cover crop with a Leaf Area Index (LAI) greater than 3. The hot pixel is chosen in a dry and bare agricultural field with a LAI near 0.

The hot and cold pixels were chosen with the aid of a spreadsheet and ArcView as follows: displayed image, created point shapefile, and selected points in the center of many fields. Several images throughout the season were needed to make sure enough bare soil and full cover points were chosen. Displayed an image in ERDAS and converted the shapefile to an AOI, used Convert Pixels to ASCII to export the LAI and Ts_DEM values for the points to a text file. Imported the text file to EXCEL and created a graph. The graph was used to help select candidate hot and cold pixels. Once a candidate was selected it was checked in the image using the Ts_DEM image to make sure the pixel was representative of the area.

DEVELOPING SEASONAL ET

Seasonal ET is extrapolated from the ET24 images using the ETrF images and the daily ETr values output from REF-ET. Seasonal ET was needed for the time period of 3/15 to 10/15. A time period is chosen for each image date to represent. The daily ETr values are summed for each of these time periods (Table 1).

Table 1. The image dates, time periods to represent, and the summed ETr values.

Image Date	Time Period	Summed ETr
3/21	3/15 to 4/9	119.205
4/30	4/10 to 5/16	200.350
6/1	5/17 to 6/13	205.155
6/25	6/16 to 7/11	228.250
7/27	7/12 to 8/12	257.475
8/28	8/13 to 9/17	217.635
10/7	9/18 to 10/15	116.43

Part of the 3/21 image was cloud covered. The clouds were masked to zero using an AOI. For this cloudy area, the early season portion, of the seasonal ET was developed from the 4/30 image. So the 4/30 image represented 3/15 to 5/16 in the cloudy area.

A spatial model computed the seasonal ET by multiplying each summed ETr value by each ETrF image and adding all of these. The model also checked for negative ETrF values and changed these to zero. SEBAL sometimes produces negative ETrF values, typically in rangeland areas; this is one of the limitations of SEBAL. Figure 2 shows the Seasonal ET image.

A Seasonal ET legend was developed with a series of color ramps using the following colors: 0 gold, 300 tan, 600 turqouise, 900 charteuse, 1200 dark green, 1500 very dark green (R:0.0, G:0.2, B:0.0).

SUMMARY

SEBAL was applied to 14 Landsat images from 7 dates throughout the 2000 growing season. The results were seven 24-hour ET images and a seasonal ET image for the period from 3/15 to 10/15. The seasonal ET data will be used for hydrologic modeling and regional planning.

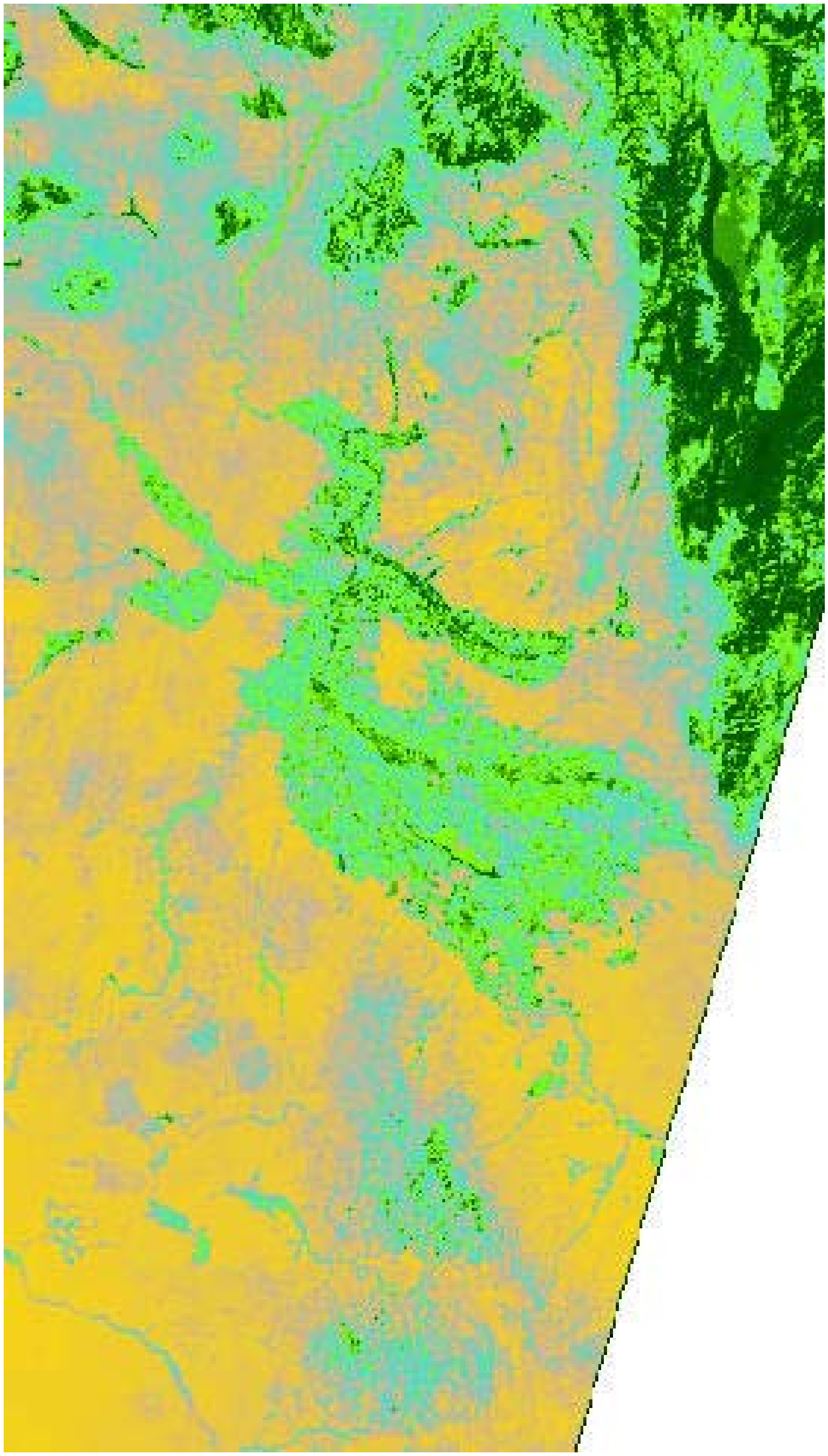


Figure 2. Seasonal ET from 3/15/2000 to 10/15/2000.

APPENDIX I

Articles and Reports

Allen, R.G., M Tasumi, W. Bastiaanssen, W. Kramber, A. Morse, R. Trezza, J.L. Wright; 2002; Evapotranspiration from Satellite and SEBAL for the Snake Plain Aquifer in Idaho; Proceedings of the Conference on Energy, Climate, Environment, and Water; U.S. Committee on Irrigation and Drainage; California Polytechnic State University, San Luis Obispo, CA

Allen, R.G., A. Morse, M. Tasumi, W. Bastiaanssen, W.J. Kramber, H.N. Anderson; 2001; Evapotranspiration from Landsat (SEBAL) for Water Rights Management and Compliance with Multi-State Water Compacts; Proceedings of IGARSS 2001; Sydney, Australia

Allen, R.G., A. Morse, M. Tasumi, W. Bastiaanssen, W.J. Kramber, H.N. Anderson; 2001; Landsat Thematic Mapper for Evapotranspiration from via SEBAL process for Water Rights Management and Hydrologic Water Balances; Proceedings of the Conference of the American Geophysical Union; Boston, MA.

Allen, R.G., M. Tasumi, A. Morse, W. Bastiaanssen, W.J. Kramber, H.N. Anderson; 2001; Evapotranspiration from Landsat (SEBAL): Applications in the U.S. Proceedings of the Annual Conference of the International Commission on Irrigation and Drainage, Seoul, Korea.

Bastiaanssen, W.G.M. 2000. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. *J. Hydrology* 229:87-100. Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag. 1998. A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. *J. Hydrology* 212-213, p. 198-212.

Morse, A.; 2001; SEBAL Evapotranspiration from Landsat for Water Rights Management in Idaho; presented at the 2001 meeting of the National States' Council on GIS; St. Louis, MO

Morse, A.; 2001; Managing Idaho Water Rights with Remote Sensing; presented to The World Bank; Washington, D.C.

Morse, A, R.G. Allen, M. Tasumi, and W.J. Kramber; 2001; SEBAL Evapotranspiration from Landsat for Water Rights Management; presented at the IGARSS 2001 Symposium; Sydney, Australia.

Morse, A and R.G. Allen; 2001; Application of the SEBAL Methodology for Estimating ET and Consumptive Water-Use Through Remote Sensing; presented at Raytheon Company, Upper Marlboro, MD.

Morse, A.; 2001; SEBAL Phase II: Now What?; presented at the Western States Water Council Water Information Management Systems 2001 Workshop; Reno, NV.

Morse, A.; 2000; Mapping Evapotranspiration with SEBAL and Landsat TM; presented at the Western States Water Council Water Information Management Systems 2000 Workshop; Sun Valley, ID.

Morse, A.; 2000; Using SEBAL and Landsat TM to Estimate Evapotranspiration; presented at the 2000 meeting of the National States Geographic Information Council Meeting; North Lake Tahoe, CA.

Morse, A., M. Tasumi, R.G. Allen, and W.J. Kramber; 2000; Application of SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the Bear River Basin of Idaho through Remote Sensing; Final Report.

Tasumi, M.; 2000; Preliminary Results on Computing Evapotranspiration Using SEBAL; research report to University of Idaho.

APPENDIX I1

Data used in SEBAL models and spreadsheets.

Representative elevation: 750 meters,
Image center in decimal degrees: 43.7557, -116.793,
Mean elevation of weather stations: 767 meters.

Missing data in the following tables was either not recorded (nr), not available (na), or not used (nu) in that version of the SEBAL models.

3/21, Time: 18:24:31.5, Landsat 7

	Dewpoint Temp 24	ET 24
Daily.out Nampa	-4.8	4.14
Daily.out Parma	-4.2	3.46
Mean	-4.5	3.80

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	3.8	3.3	3.35	-3.1	-4.4	-4.28	0.37	0.45	0.443
Hourly.out Parma	1.6	1.4	1.42	-3.4	-3.2	-3.22	0.38	0.46	0.453
Mean			2.385			-3.75			0.4477

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	274410	288870	284.404	716	284.625	512.572	17.725	0.108	4.975
Hot Pixel	260370	292560	296.452	704	296.751	406.979	51.627	0.005	4.969

4/30, Time 18:07:20, Landsat 5

	Dewpoint Temp 24	ET 24
Daily.out Nampa	-3.8	8.23
Daily.out Parma	-2.1	7.23
Mean	-2.95	7.73

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	5.7	4.9	5.236	-4.2	-5.0	-4.664	0.71	0.81	0.768
Hourly.out Parma	2.5	1.6	1.978	-1.9	-1.9	-1.9	0.66	0.72	0.695
Mean			3.607			-3.282			0.7315

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	271050	300420	289.462	722	289.644	590.016	26.760	0.108	7.528
Hot Pixel	258630	295830	307.171	734	307.282	373.433	76.760	0.005	7.537

6/1, Time 18:07:59, Landsat 5

	Dewpoint Temp 24	ET 24
Daily.out Nampa	2.8	7.62
Daily.out Parma	3.8	6.92
Mean	3.3	7.27

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	1.7	3.2	2.57	3.2	1.9	2.45	0.63	0.76	0.705
Hourly.out Parma	1.9	1.9	1.9	4.4	3.7	3.99	0.64	0.74	0.698
Mean			2.235			3.22			0.702

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	263520	291720	291.955	743	292.001	621.819	32.915	0.108	4.675
Hot Pixel	266220	288000	309.810	756	309.771	403.788	90.278	0.005	4.681

6/25, Time 18:23:39, Landsat 7

	Dewpoint Temp 24	ET 24
Daily.out Nampa	7.6	9.76
Daily.out Parma	9.1	8.98
Mean	8.35	9.37

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	4.9	4.9	4.9	7.2	6.8	7.0	0.79	0.89	0.84
Hourly.out Parma	3.0	3.3	3.15	7.3	7.6	7.45	0.83	0.94	0.885
Mean			4.02			7.25			0.8625

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	268745	301666	294.714	717	nr	649.234	35.527	nr	nr
Hot Pixel	262619	307321	317.362	729	nr	297.113	90.599	nr	nr

7/27, Time: 18:23:06, Landsat 7

	Dewpoint Temp 24	ET 24
Daily.out Nampa	11.0	6.34
Daily.out Parma	11.5	7.59
Mean	11.25	6.965

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	3.1	na	3.1	10.7	11.8	11.25	0.75	na	0.75
Hourly.out Parma	1.1	0.00	0.555	10.7	11.6	11.15	0.71	0.74	0.725
Mean			1.838			11.2			0.738

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	261839	293221	296.715	709	nr	585.998	33.022	nr	nr
Hot Pixel	257943	296338	314.674	725	nr	279.365	82.236	nr	nr

8/28, Time: 18:22:51, Landsat 7

	Dewpoint Temp 24	ET 24
Daily.out Nampa	3.0	7.10
Daily.out Parma	3.8	6.25
Mean	3.4	6.675

	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	3.1	2.2	2.65	3.3	3.3	3.3	0.64	0.68	0.66
Hourly.out Parma	0.8	1.6	1.2	3.9	2.2	3.05	0.55	0.71	0.63
Mean			1.925			3.175			0.645

	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	261270	295920	293.967	726	293.811	531.045	30.751	0.108	4.019
Hot Pixel	263550	292500	310.084	742	310.032	302.609	73.006	0.005	4.028

10/7, Time: 18:10:24, Landsat 5

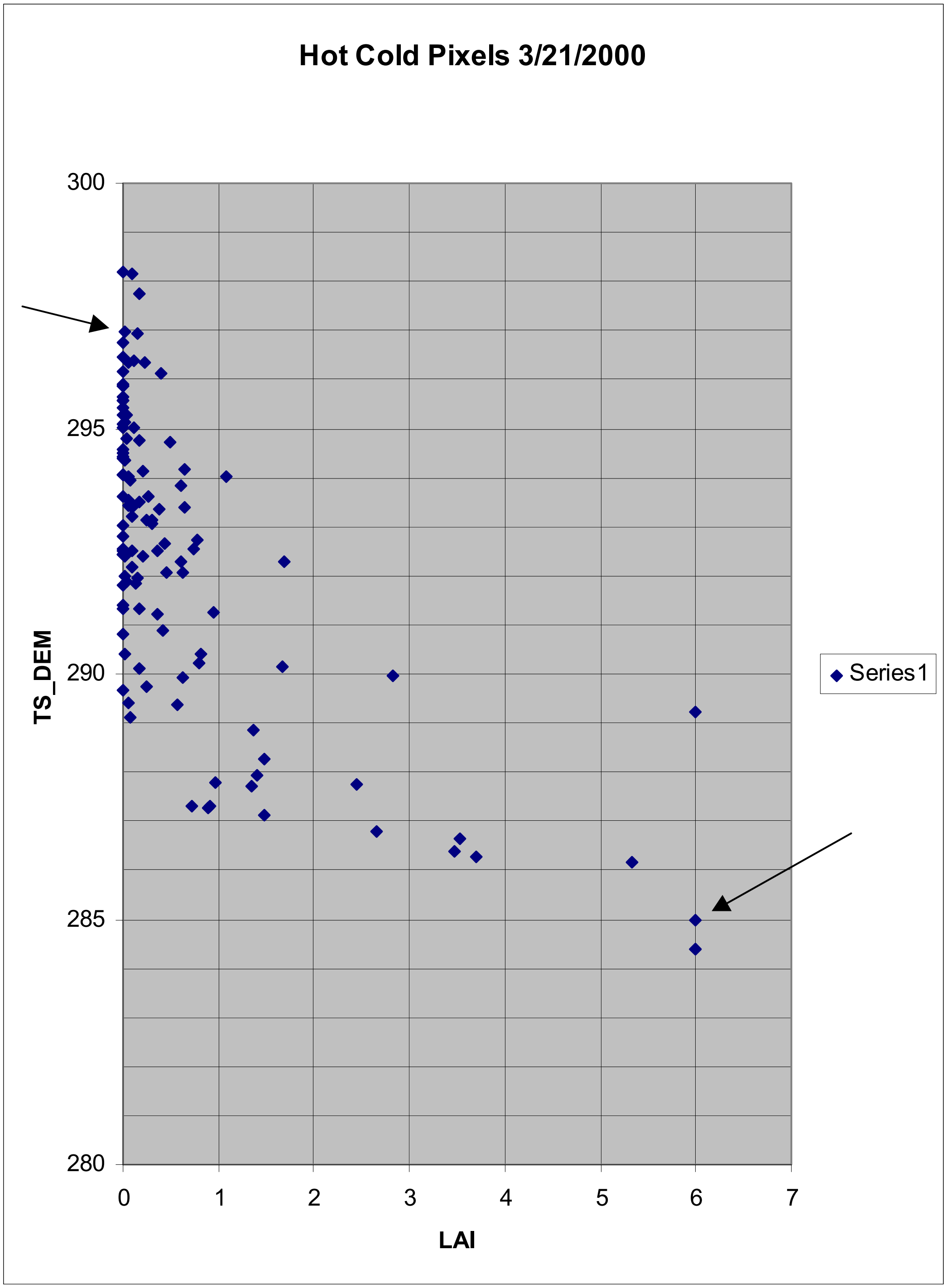
	Dewpoint Temp 24	ET 24
Daily.out Nampa	-6.9	4.75
Daily.out Parma	-2.6	3.33
Mean	-4.75	4.04

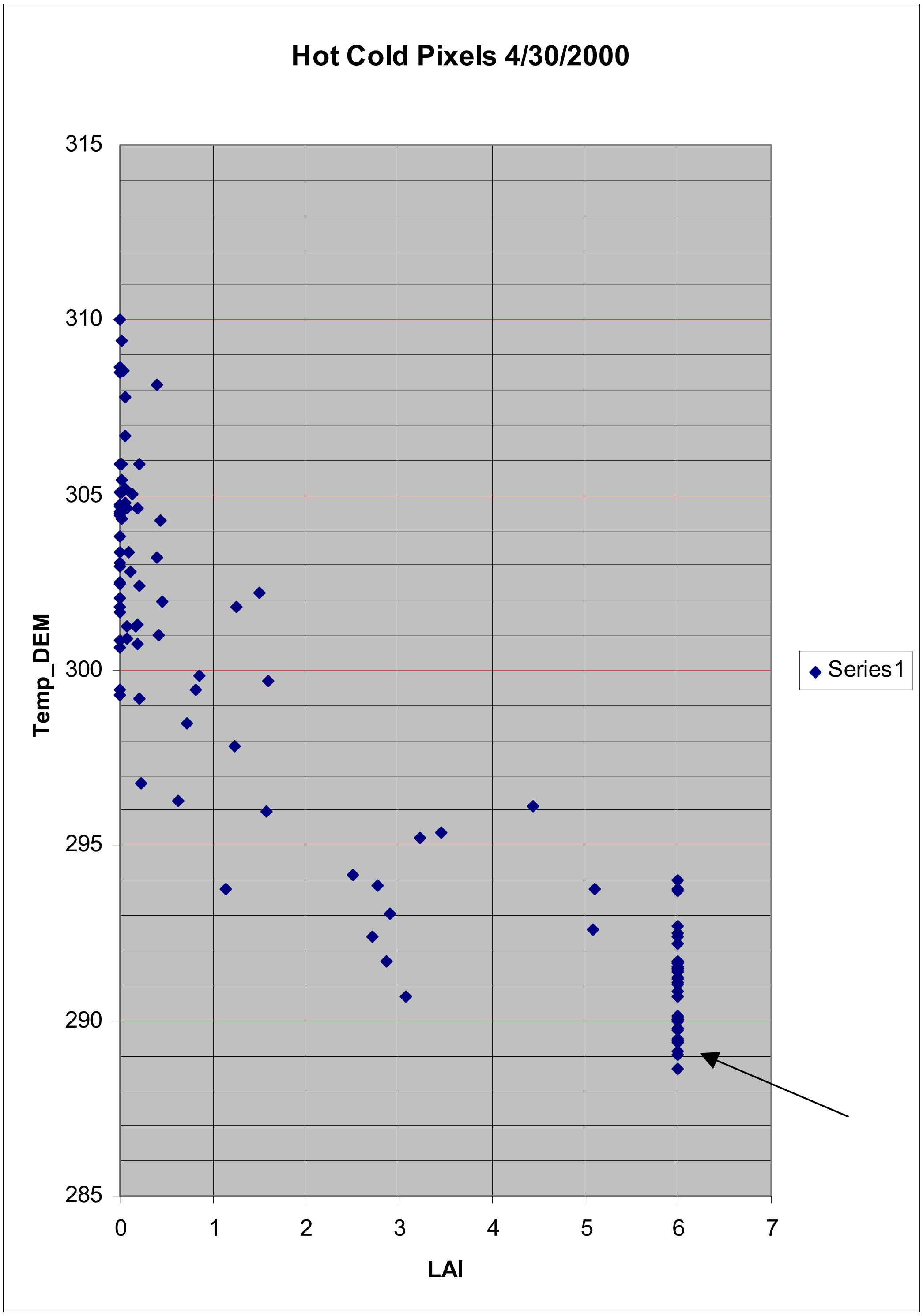
	Wind (meters/second)			Dewpoint T inst.			ET instant		
	11	12	Mean	11	12	Mean	11	12	Mean
Hourly.out Nampa	6.7	5.4	5.83	-10.0	-11.0	-10.67	0.67	0.71	0.697
Hourly.out Parma	1.6	1.1	1.27	-2.4	-1.9	-2.07	0.41	0.48	0.457
Mean			3.55			-6.3			0.577

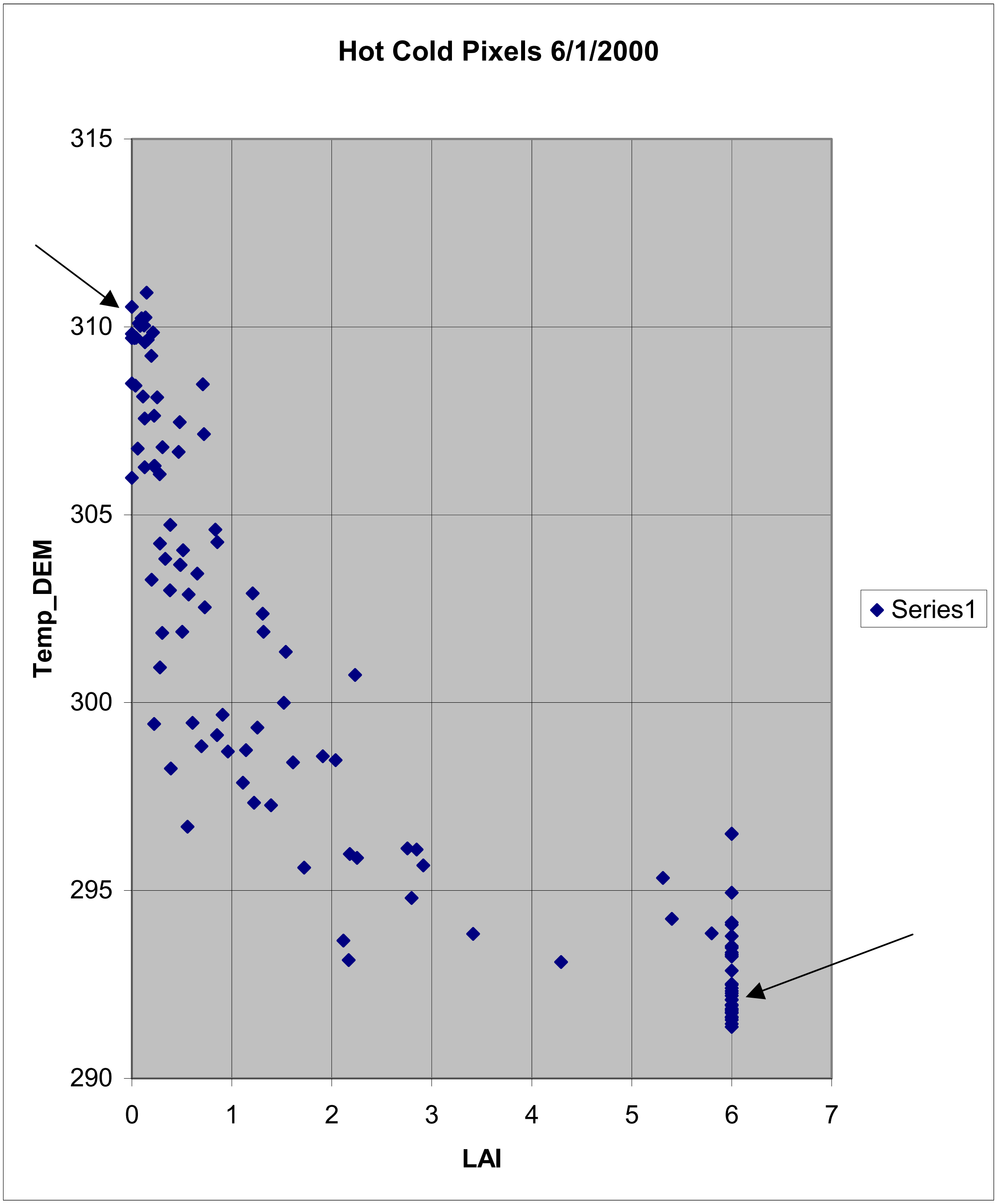
	X	Y	Ts_DEM	DEM	Ts	Rn	G	Zom	U200
Cold Pixel	257970	300660	287.217	726	287.724	349.331	18.026	0.108	8.617
Hot Pixel	265530	303390	301.013	742	301.279	247.992	42.649	0.005	8.650

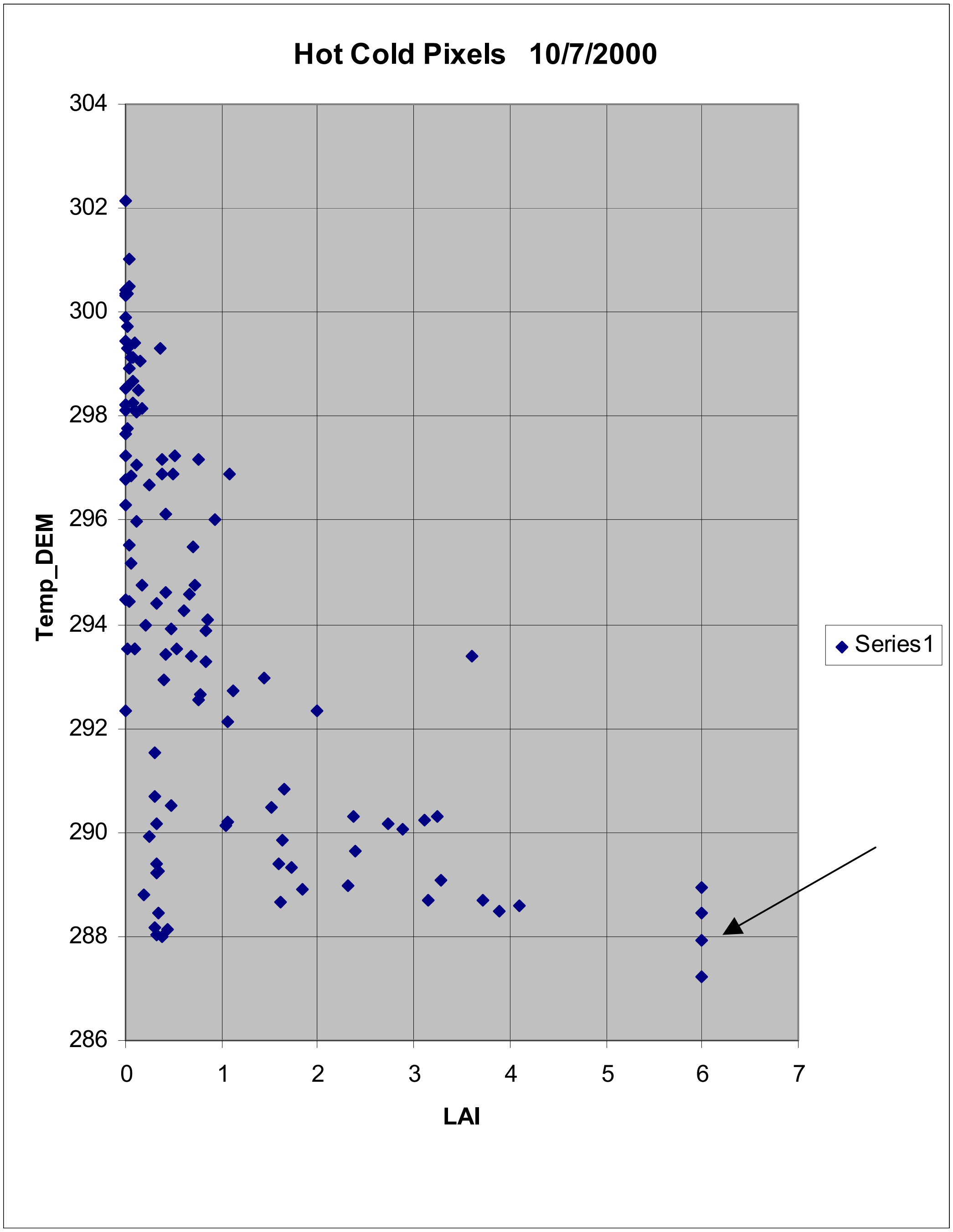
APPENDIX III

Hot and Cold Pixel Graphs




Hot Cold Pixels 4/30/2000
315
310
305
300
295
290
285
Temp_DEM
0
1
2
3
4
5
6
7
LAI
Series1


Hot Cold Pixels 6/1/2000
Temp_DEM
315
310
305
300
295
290
0
1
2
3
4
5
6
7
LAI
Series1


Hot Cold Pixels 10/7/2000
Temp_DEM
304
302
300
298
296
294
292
290
288
286
0
1
2
3
4
5
6
7
LAI
Series1